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NIAGARA 25 HZ SYSTEM ISLANDED OPERATION TESTS: Series 2

Report No 91-119-K

G.R. Bérubé
Engineer
System Studies Section
Electrical Research Department

ABSTRACT

On March 4 and 5, 1991, a series of staged tests were performed to study the behaviour of the Niagara 25 Hz system while operating as an electrical island with as few as two Sir Adam Beck GS I generators synchronized to the system.

The tests confirmed that the system can be operated in an islanded configuration for extended periods of time without requiring any restrictions on the operation of customer equipment. The results also confirmed that digital simulations of the system's islanded operation are accurate and can be reliably employed to develop any future planning and operating strategies.

Key Words: Islanded Operation, System Test, Governor

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To Mr. I.J. Stuart-Sheppard
Manager
Mechanical and Equipment Engineering Dept
Design and Development-Generation

NIAGARA 25 HZ SYSTEM ISLANDED OPERATION TESTS:
Series 2

1. BACKGROUND

The Niagara 25 Hz system is one of two remaining pockets of 25 Hz load/generation embedded in the Ontario Hydro 60 Hz system. The system is supplied primarily by generation located at the Sir Adam Beck I (SAB I) plant and the Ontario Power (OP) plant located on the Niagara River system. As of March 1991, there were four 25 Hz units at the SAB I plant (installed capacity of 200 MVA) and twelve small 25 Hz units available at the OP plant (installed capacity of approximately 100 MVA).

The configuration of the Niagara 25 Hz system at the time of this system test (March 1991) is shown in the simplified schematic of Figure 1. There are two interconnections between the Niagara 25 Hz system and the 60 Hz system, namely: the SAB I rotating frequency changer (FC1) rated at 54 MVA and the 69-kV circuit BSC105 which connects SAB I (via Niagara Parks TS) to several frequency changers on the 25 Hz Niagara Mohawk system in the United States. In addition, for emergency purposes, facilities have been installed to permit a temporary connection between the 25 Hz system and a set of frequency changers at Buchanan TS.

The load connected to the 25 Hz system consists entirely of large industrial customers including Stelco and Dofasco which are located in Hamilton. To place the installed generation capacity figures in perspective, it is worth noting that the peak load on the Ontario Hydro portion of the Niagara 25 Hz system rarely exceeded 50 MW during the beginning of 1991.

1.1 Requirement for Tests

The operation of the Niagara 25 Hz system has been monitored and studied extensively over the past four years. In 1987, measurements were performed at Gage TS to monitor the typical variations of the Stelco and Dofasco 25 Hz loads /1/. In early 1989, an elaborate staged test

was performed, in which the Ontario Hydro portion of the 25 Hz system was operated as an electrical island (ie. all frequency changers disconnected from the 25 Hz system) for an extended period of time /2/. Based on the success of this staged test, Operations staff were able to schedule a one-week outage of the 60 Hz interconnections to perform urgent maintenance at the SAB I plant.

During 1990, SAB I 25 Hz unit G8 was converted for 60 Hz operation, leaving four 25 Hz generators available at the SAB I plant; this is the current configuration as of the writing of this report. Based on the significant economic benefit associated with the conversion of another 25 Hz SAB I unit for 60 Hz operation, Regional Supply Planning requested that simulations and tests be performed to confirm that the system could be reliably operated in the future with only three 25 Hz units available at SAB I. Due to the requirement that the system be operable following both a planned and forced outage, the studies and tests focused on the issue of whether islanded operation with only two SAB I units on the system was feasible.

The islanded operation tests, which are described in this report, were performed as part of an overall system test which was used to evaluate the performance of the system under a variety of possible future operating conditions /3/. The results of the radial operation tests, which involved the power system stabilizers installed at SAB I GS, will be documented in a separate report.

2. ISLANDED OPERATION TESTS

The following is a summary of the test procedure which was followed for the islanded operation tests along with the numbers of the sub-section which contain the corresponding test results:

- (2.3) With circuit BSC105 already out-of-service, and three SAB I units synchronized, disconnect Beck FC1 to create the island.
- (2.3) Perform steady-state monitoring of system frequency and unit loadings under light customer load conditions.
- (2.4) Reject one of the SAB I generators from partial load and monitor the response of the remaining two machines and the system.
- (2.5) Monitor the starting of Stelco's large synchronous motor-generator sets (7500 HP, 9800 HP).
- (2.6) Monitor the system during large variations in customer load.
- (2.3) Exit the island by reconnecting the 25 Hz system to the 60 Hz system via Beck FC1.

In performing these tests, the system frequency and the 115-kV bus voltage at SAB I were monitored closely to ensure that they were maintained within reasonable limits. Although formal

operating instructions were not in place at the time of the tests, guidelines called for the frequency to be maintained within a 5% range centred around 25 Hz. Initial planning simulations indicated that the frequency deviations caused by operating with two SAB I units in-service during customer load variations could be as high as 8% peak-to-peak depending on the governor settings. It was agreed by the stakeholders that the simulated variations would be considered acceptable during the tests. It is noteworthy that there are no longer any functioning under-frequency relays on customer equipment installed on this system.

Existing operating instructions do not place any formal restrictions on the 115-kV voltage at Beck; local operating guidelines call for the voltage to be maintained within the desirable range of 114 kV to 116 kV.

2.1 Instrumentation/Monitored Quantities

Table 1 lists the quantities which were monitored during the performance of each of the tests.

Unlike the previous series of tests, no instrumentation or recording devices were installed at Gage TS /2/. Instead, the magnitude and pattern of Stelco load variations were inferred from the output variations of the SAB I generators. This approach was possible due to the fact that all other generation (ie. CNP and OP) was disconnected from the system during the critical tests.

Members of the Hydraulic Stations Department and local Maintenance staff installed transducers on all three units to monitor penstock pressure variations above the scroll case. Hydraulic stations staff also monitored wicket gate position (with separate transducers) and gate servomotor oil pressure. Their role was to provide a mechanical assessment of the performance of the governors and to ensure that penstock pressure variations remained within safe limits throughout the tests.

Table 1 INSTRUMENTATION LIST - S.A. BECK GS 25 HZ

Quantity	Description/Transducer
Bus Voltage (115 kV)	Station phase-to-phase transducer (Woodex)
System Frequency (25 Hz)	Custom frequency transducer (Research)
Real Power Output	Units G1, G2, G6 Station Watt Transducers (Woodex)
Generator Terminal Voltage	Units G1, G6 Custom Three-Phase Transducers (Research)
Wicket Gate Position	Units G1, G2, G6 Governor Electronic Feedback Signal (Voith)
Shaft Speed	Units G1, G2, G6 Governor Electronic Speed Signal (Voith)
Penstock Pressure	Units G1, G2, G6 Custom Pressure Transducers (Hydraulic Stations)

2.2 Electro-Hydraulic Governor Settings/Representation

Reference 2 provides a complete description of the configuration and setting of the Voith electro-hydraulic governors installed at SAB I, along with accurate models for use in digital simulations. When operating in an island, the governors are placed in an isolated-operation mode which increases the temporary droop (R_t) and damping time constant (T_r) to suitable levels.

System Planning Division performed a number of simulations to determine the appropriate settings for the temporary droop and damping time constant. Their recommendations, based on maximizing the damping of the low-frequency governor mode (0.1 - 0.14 Hz), were for T_r and R_t values of 5 seconds and 0.3 pu, respectively /4/. A temporary droop of 0.3 pu results in a very heavily damped response to system load changes; lower transient droop settings were used throughout the tests in an attempt to minimize system frequency variations during rapid load changes. This approach was considered acceptable, since even with significantly lower levels of temporary droop there is adequate damping of the governor mode. Table 2 summarizes the results of simulations which demonstrate the relationship between the temporary droop setting and the damping ratio of this low-frequency mode for various system conditions /4/.

Table 2 NIAGARA 25 HZ GOVERNOR MODE DAMPING (SIMULATED)(1)

Temporary Droop R_t(pu)	2 Units I/S Equal Loading		3 Units I/S Equal Loading		3 Units I/S Unequal Loading(2)	
	Damped Frequency ω_d(rad/s)	Damping Ratio ξ	Damped Frequency ω_d(rad/s)	Damping Ratio ξ	Damped Frequency ω_d(rad/s)	Damping Ratio ξ
0.1	0.85	0.07	0.90	0.15	0.73	-0.05
0.15(3)	0.80	0.22	0.80	0.33	0.66	0.12
0.2	0.70	0.42	0.70	0.52	0.56	0.27
0.3	0.40	0.77	-	>0.52	0.36	0.40

NOTES: (1) T_r = 5 seconds, Total System Load = 44 MW (2 Units I/S); 80% Constant Power Load
(2) Any single unit loaded at efficiency, Total System Load = 93 MW
(3) Values estimated from eigenvalue calculations at other temporary droop settings

Additional simulations performed with unequal generator loading confirmed that adequate damping (damping ratio >0.1) exists even under the most pessimistic study conditions, with temporary droop settings of 0.15 on all governors. However, according to the simulations, further reductions are not advisable since under unequal loading conditions the governor mode is unstable with temporary droop set at 0.1 pu.

For reference purposes, a block diagram representation of the Voith governor has been reproduced (Figure 2) from reference 2. Based on the detailed tests described in the aforementioned reference, the following parameters should be used to simulate the behaviour of any of these governors during isolated operation:

Permanent Droop	R_p = 0.04 pu
Temporary Droop	R_t = "as set"
Damping Time Constant	T_r = 5 s
Gate Servomotor Time Constant	T_g = 0.1 s
Moving Coil Time Constant	T_p = 0.045 s
Control Valve Time Constant	T_y = 0.05 s
Speed Measurement Time Constant	T_n = 0.0 s
Gate Velocity Limits	r_{max} = 0.1
	r_{min} = 0.14

2.3 Entering and Exiting the Islanded System

The system conditions prior to creating the island were as follows:

- Three SAB I 25 Hz units (G1, G2, G6) were synchronized to the system
- All Ontario Power GS units were synchronized to the system and operating at speed no-load
- Canadian Niagara Power (CNP) generators were off-line

The total connected customer load was less than 20 MW due to the tests' start time (Monday morning, 5:13 Daylight Savings Time, March 4, 1991).

Immediately prior to entering the island, the three SAB I units were configured for islanded operation: the isolated mode of operation was manually selected on each of the three Voith governors and the Power System Stabilizers were taken out of service on units G1 and G6. SAB I generation was adjusted to reduce the flow on circuit BSC105 to zero prior to disconnection. This process was then repeated to disconnect Beck frequency changer FC1. Opening the final interconnection, Beck FC1, produced only a small change in the 25 Hz system frequency; all other quantities remained virtually unchanged.

The reverse procedure was employed to exit the island while customer load variations were taking place. Even under these conditions, re-establishing the connection to the 60 Hz system was uneventful.

Steady-state monitoring revealed that, as expected, there was negligible variation in the system voltage (115-kV) or frequency when the major customer loads were not operating.

2.4 Generation Rejection Tests - S.A. Beck I GS

Prior to monitoring the effect of customer load variations on the islanded system, a number of controlled disturbances were introduced by rejecting SAB I unit G2 from partial load (approximately 5 MW). Figure 3 displays the results of one of these tests, performed with the OP units synchronized to the system. With two SAB I units in-service (post-rejection) tripping G2 from a level of 5 MW produced a peak frequency deviation (negative) of 1%. The temporary droop setting for the two remaining units (G1, G6) during this test was 15%. As expected, the deviation in the 115-kV voltage was very small as it is primarily a function of the pre-rejection reactive power loading of unit G2; in this case G2 was taking in 6 MVAR resulting in a slight increase in bus voltage following its rejection.

Figure 4 displays measured system frequency responses (transcribed from chart records) to similar generation rejections with the OP units either synchronized or off-line. The damped frequency of oscillation and peak frequency deviations are both increased slightly when the OP units are removed from the system due to the decrease in overall inertia. The effect of the OP units on the dynamic response of the system was more noticeable during these tests than during those reported in reference 2 due to the decreased number of SAB I units synchronized to the system. Nevertheless the benefit of retaining the OP units on the system during islanded operation is minor, and the remaining tests were conducted with only SAB I generation in-service.

2.5 Motor Starting - Stelco

Stelco's load includes a number of large synchronous motor-generator sets, with ratings of up to 9800 HP (7.4 MW). Previous tests, conducted with five Beck generators in service, /2/ revealed that starting these motors in the islanded system did not produce objectionable changes in the 115-kV system voltage or frequency. Starting of each of the large motors during the previous tests resulted in a short duration (less than 10 seconds) 20 MVAR inrush onto the Gage TS 13.8-kV bus supplying Stelco.

Motor starting during the current tests, with three SAB I units synchronized to the system, resulted in voltage declines which were of the same order as those obtained with five SAB I units in-service; ie. 2% to 3% on the SAB I 115-kV bus. Figure 5 displays the results of a typical set of motor starts; it would appear from this trace that three separate motors were connected to the system, however, according to Stelco this corresponded to the starting of a single 9800 HP MG set. The voltage decline during each event is approximately 2% on the 115-kV bus and the resulting increase in the reactive power output on unit G6 (the unit with the highest rating) was 12 MVAR for approximately 10 seconds.

During one of the other motor starting procedures the measured reactive power change on G6 was slightly over 20 MVAR. This was not representative of the normal starting procedure and appears to have been due to an error whereby two motors were started within seconds of each other. Clearly, in the future if the system has to be operated as an island with only two SAB I units in-service the reactive power drawn on these units during the Stelco starting procedure will

be significant. However, since this procedure normally coincides with a low real-power system demand, and consequently a low real-power output on these generators, there is virtually no danger of exceeding any of the generators' MVA capabilities even for short durations. It is also worth noting that units G1 and G6 are outfitted with static excitation systems which have extensive field-forcing capabilities.

2.6 Monitoring Customer Load Variations

The remaining tests consisted of monitoring the system's response to the rapid load variations occurring during Stelco's Hot Strip Mill operation. The presence of the Strip Mill load was inferred by examination of the real power outputs of the SAB I generators, which were the only units supplying the island during these tests.

Figure 6 displays a typical trace showing the variation of several quantities for a complete cycle of the Strip Mill load variation with three units on-line at SAB I. Each load cycle lasts approximately two minutes.

Examining the SAB I generation (total) trace on Figure 6a, it can be seen that the total peak-to-peak load change, due to the Stelco Strip Mill is just under 30 MW. This corresponds to the maximum variation in load measured during previous tests [1,2]. The maximum peak-to-peak frequency variation for this period was 3.7% (0.93 Hz) while the 115 kV bus voltage varied by 1.6% (1.8 kV). From Figure 6a it can be seen that the frequency variations are not centred around the 25 Hz level. This was due to the fact that the operators were asked not to adjust the governors' speed reference setting during the tests; under normal operating conditions they will be able to adjust generation to equalize the frequency variations in the two directions.

The gate position variations for the three units (refer to Figure 6c) were remarkably similar throughout the load cycle with peak-to-peak variations of 22.5%, 23% and 22.5% for G1, G2 and G6, respectively. This was achieved through on-line adjustment of the temporary droop potentiometers on the units. The potentiometer (P12) settings which correspond to temporary droop values of 15% on these units are 13%, 10% and 14% (G1, G2 and G6). In the event that new temporary droop settings are required in the future, the equations provided in reference 2 may be used to obtain guidelines for the new potentiometer settings.

From Figure 6d it can be seen that the variations in reactive power on the two units equipped with static exciters (G1, G6) are out of phase with the variations on unit G2, with its rotating exciter and rheostatic voltage regulator. Sharing of reactive power variations will be restored as soon as the new static exciter is installed on unit G2.

Figure 7 displays a measurement of the system response to customer load variations of 27 MW peak-to-peak with only two SAB I generators on-line (G1, G6). Frequency and 115-kV bus voltage peak-to-peak variations during this period were 4.5% (1.13 Hz) and 1.5% (1.7 kV), respectively. Gate positions for the two machines varied over a range of 26% during the load cycle. Table 3 summarizes the measured gate/frequency deviations along with System Planning Division's simulated results [4]. It should be noted that the measured results are the largest

values encountered during the entire test period and do not correspond to the results shown in Figures 6 and 7. Also, comparing the measured and simulated results for the two and three units in-service cases, it must be noted that the simulated results listed correspond to a slightly higher value of temporary droop. Nevertheless, it is clear that the simulations do provide a good representation of the operation of the islanded system under varying load conditions.

Table 3 FREQUENCY AND GATE POSITION VARIATIONS DURING STELCO LOAD VARIATIONS

	5 Units I/S[1]		3 Units I/S[2]		2 Units I/S[2]	
	Frequency (% p-p)	Wicket Gate Positions (% p-p)	Frequency (% p-p)	Wicket Gate Positions (% p-p)	Frequency (% p-p)	Wicket Gate Positions (% p-p)
Measured	2%	< 12%	4%	20%	6%	30%
Simulated[3]	-	-	3.9%	18%	6.4%	33%

NOTES: (1) Previous measurements documented in reference /2/. Unequal governor settings on the five units.
(2) Temporary droop = 15% on all units.
(3) Simulations documented in reference /4/. Temporary droop = 20% on all units.

Referring to Figures 6e and 7d it can be seen that penstock pressure variations were quite small throughout the test period. The largest pressure variations were under 10 psi (22 feet of head) and there was no tendency for the variations to build up during the repeated gate position changes. These variations may be compared to the 22 psi (50 feet of head) pressure increase to which the penstock is typically subjected during a load rejection. Both of these pressure rises are well within the safe limits for the SAB I 25 Hz unit penstocks. According to the staff from the Hydraulic Stations Department there were no problems in maintaining adequate accumulator tank oil levels throughout the monitored period and there should not be any mechanical equipment problems associated with continuous operation in the islanded mode with as few as two SAB I units in-service.

3. CONCLUSIONS AND RECOMMENDATIONS

There were no customer complaints received during, or immediately following, the islanded operation tests. All of the control equipment at SAB GS I performed as anticipated and there do not appear to be any technical reasons that the Niagara 25 Hz system cannot be operated in an islanded configuration for extended periods of time, with as few as two SAB I generators in-service. These results should provide the Planning and Operating functions with the necessary

information to decide on the future conversion of another SAB I 25 Hz unit and the disposition of the Buchanan frequency changers and associated equipment.

The largest frequency deviation encountered during the operation of the Stelco Strip Mill load was 6% peak-to-peak which exceeds the existing guidelines of ±2.5%. The current Local Control Order calls for the Beck 115-kV bus voltage to be maintained in the desirable range of 114-kV to 116-kV. These limits may be quite difficult to respect during islanded operation with large customer load variations. It is recommended that these guidelines be reviewed and replaced with realistic values as part of the development of detailed operating procedures and limits for islanded operation of the Niagara 25 Hz system. Any future operating procedures or guidelines should ensure that control equipment is correctly configured for either planned or emergency islanded operation; ie. all power system stabilizers must be out of service and all 25 Hz governors must be placed in the isolated operation mode.

The temporary droop setting on each of units G1, G2 and G6 was left at the tested level of 15%, which provided good regulation of system frequency during islanded operation but which was well below the 30% level recommended by the System Planning Division. This recommendation was based on providing optimum damping of the low frequency governor mode but did not take into account the benefits of faster response on frequency regulation and manual controllability. It is recommended that the use of this temporary droop level be reviewed during the performance of any operating simulations to ensure that it is adequate. It should be noted that any modifications to the temporary droop level would require some testing and custom adjustment if well balanced responses of the on-line units are desired. The station P&C staff should verify that the temporary droop setting on unit G7 is also set to 15%.

3.1 Acknowledgements

I wish to thank all of the individuals and groups who were involved in the planning, coordination and performance of the islanded operation tests. Special thanks to the P&C, Electrical Maintenance, Mechanical Maintenance and Operations staff at S.A. Beck I and, in particular, to Mr. Bob Driscoll for his efforts in the on-site coordination of the tests. The assistance of Bruce Hogg (HG&TOD), and of Les Hajagos, Bruno Pietrantonio and George Schembri of the System Studies Section, is also gratefully acknowledged.

Approved:

A.F. Baljet
Manager
Electrical Research Department

Submitted:

G.R. Bérubé
Engineer
System Studies Section

GRB:am

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4. Memorandum from Mr. L. Hajagos to Mr. G.R. Bérubé, "Niagara 25 Hz System Tests," November 23, 1990.

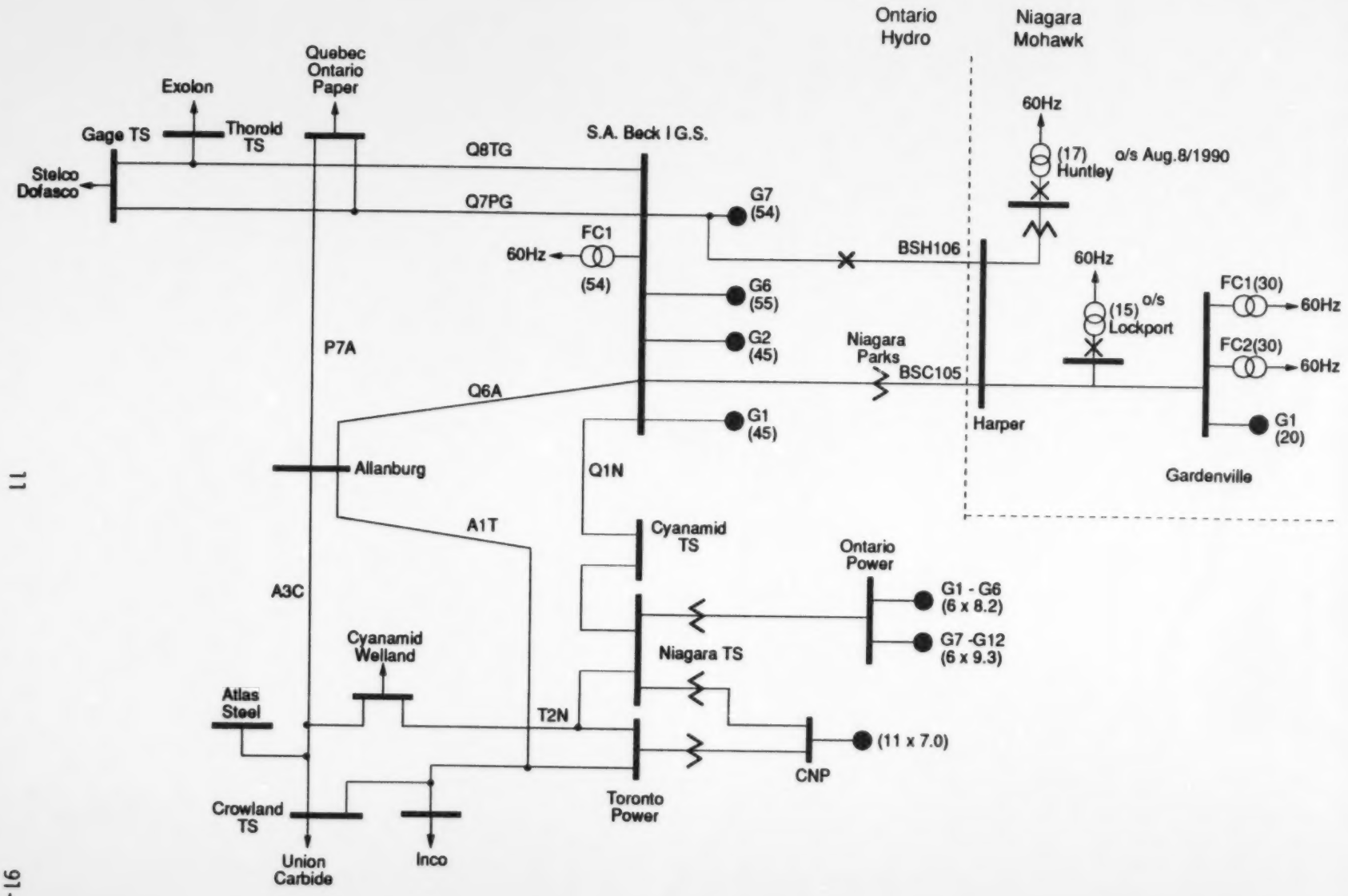

FIGURE 1

NIAGARA 25 Hz SYSTEM SCHEMATIC (MARCH - 1991)

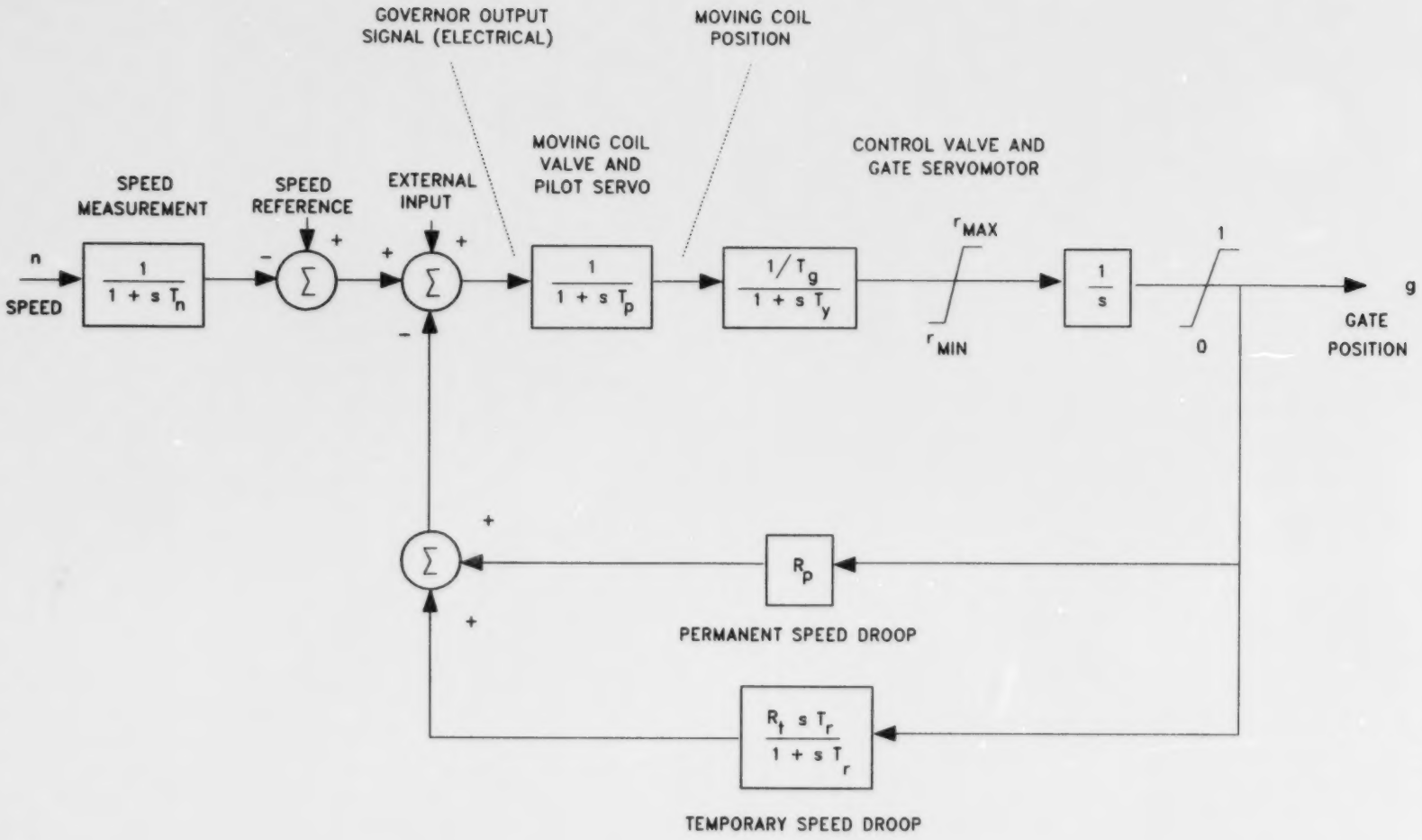

FIGURE 2 : BLOCK DIAGRAM REPRESENTATION OF VOITH ELECTRO–HYDRAULIC GOVERNOR

VOITH31.DRW

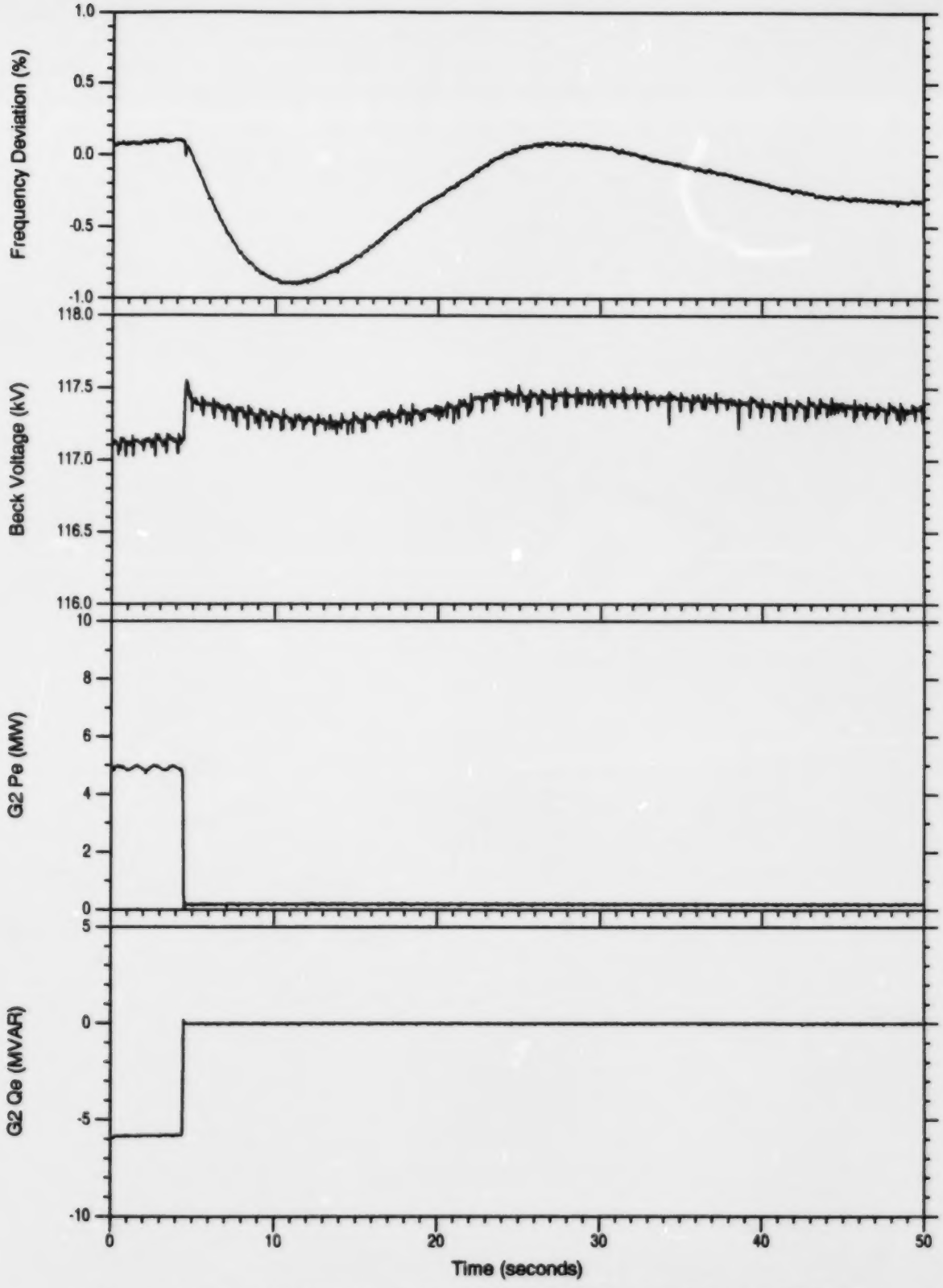

Figure 3a: NIAGARA 25 Hz ISLANDED TESTS, MARCH 4, 1991 REJECTION OF SAB I G2 FROM 5 MW, OP UNITS I/S

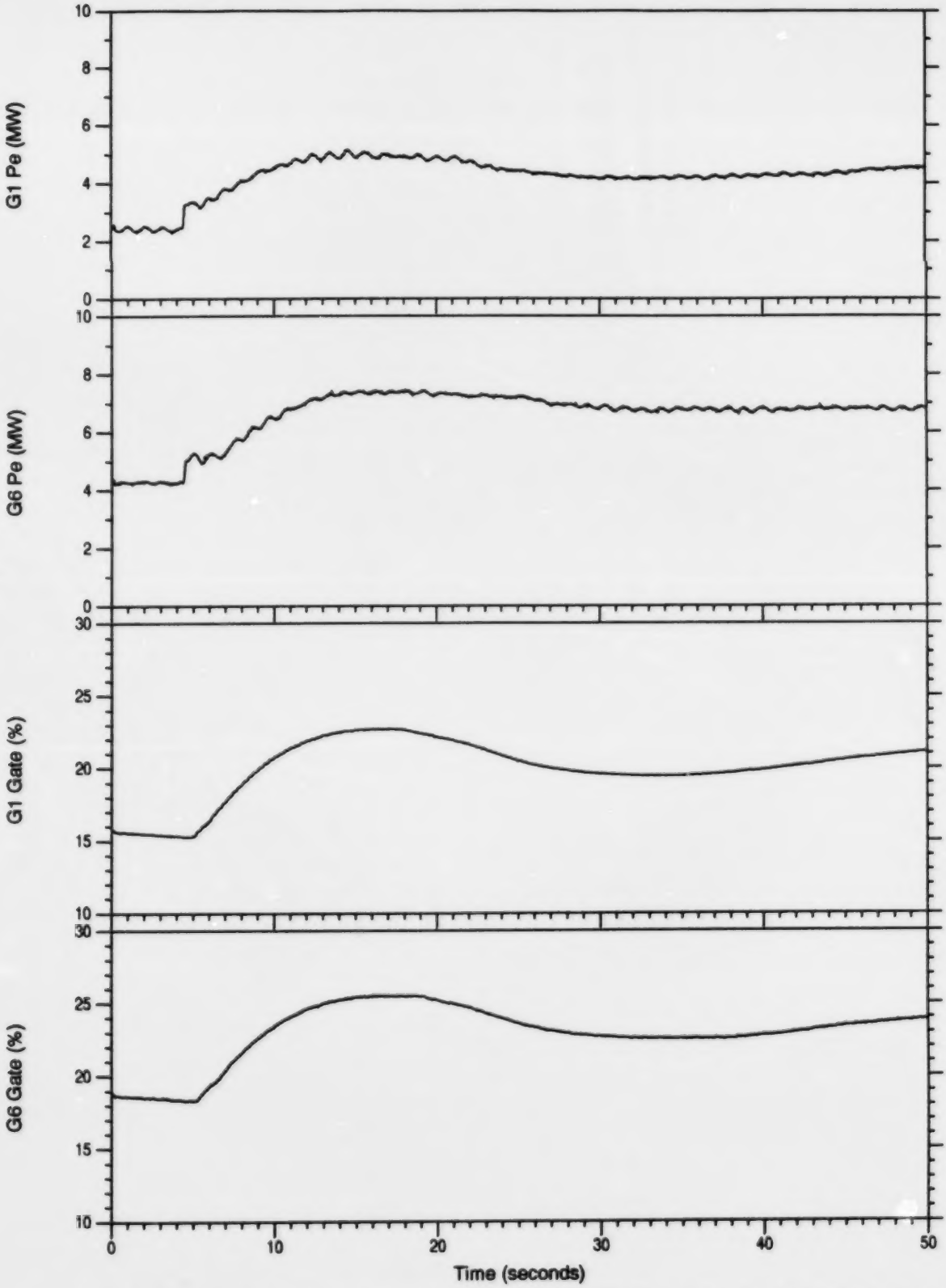

Figure 3b: NIAGARA 25 Hz ISLANDED TESTS, MARCH 4, 1991 REJECTION OF SAB I G2 FROM 5 MW, OP UNITS I/S

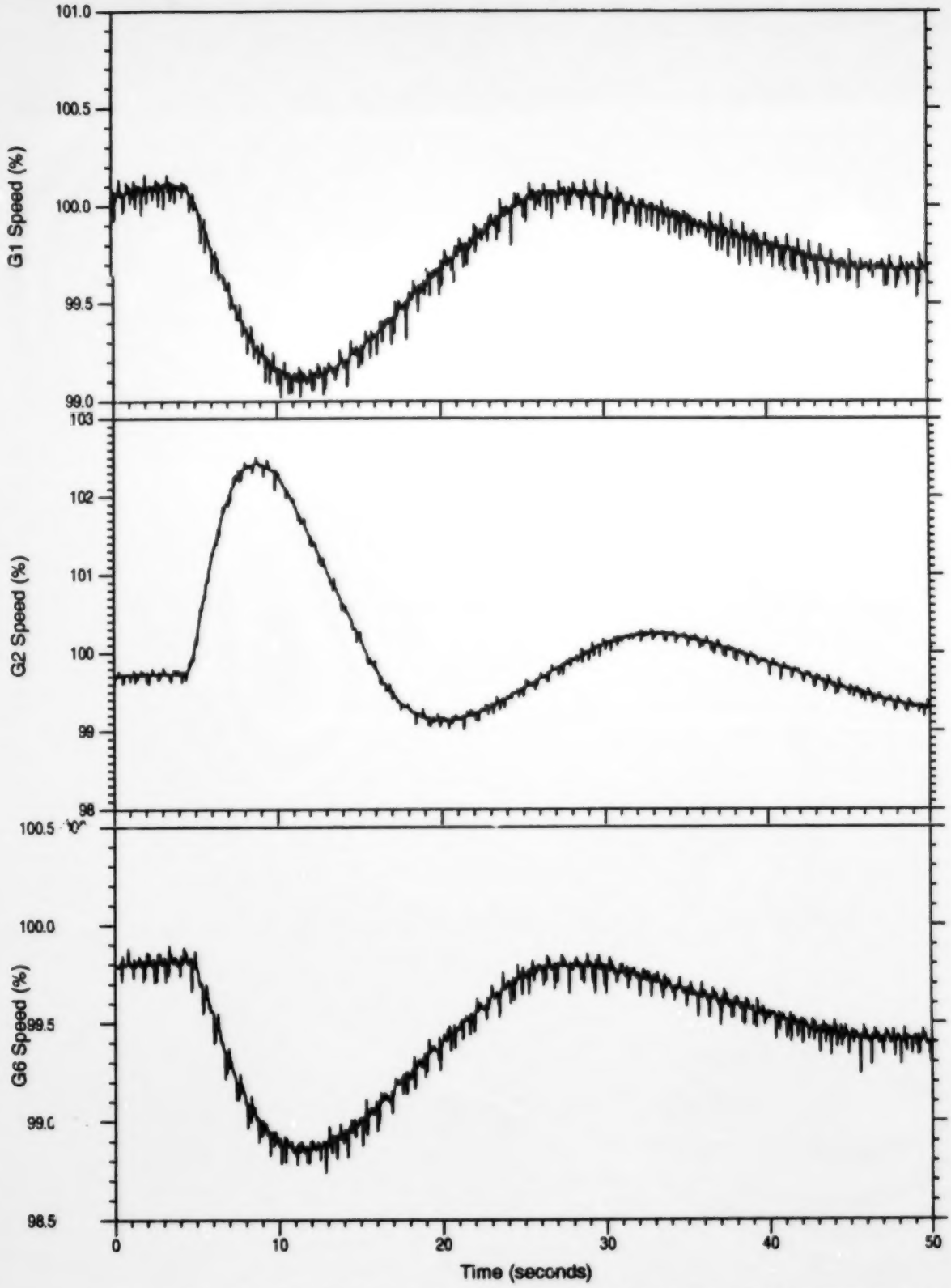

Figure 3c: NIAGARA 25 Hz ISLANDED TESTS, MARCH 4, 1991 REJECTION OF SAB I G2 FROM 5 MW, OP UNITS I/S

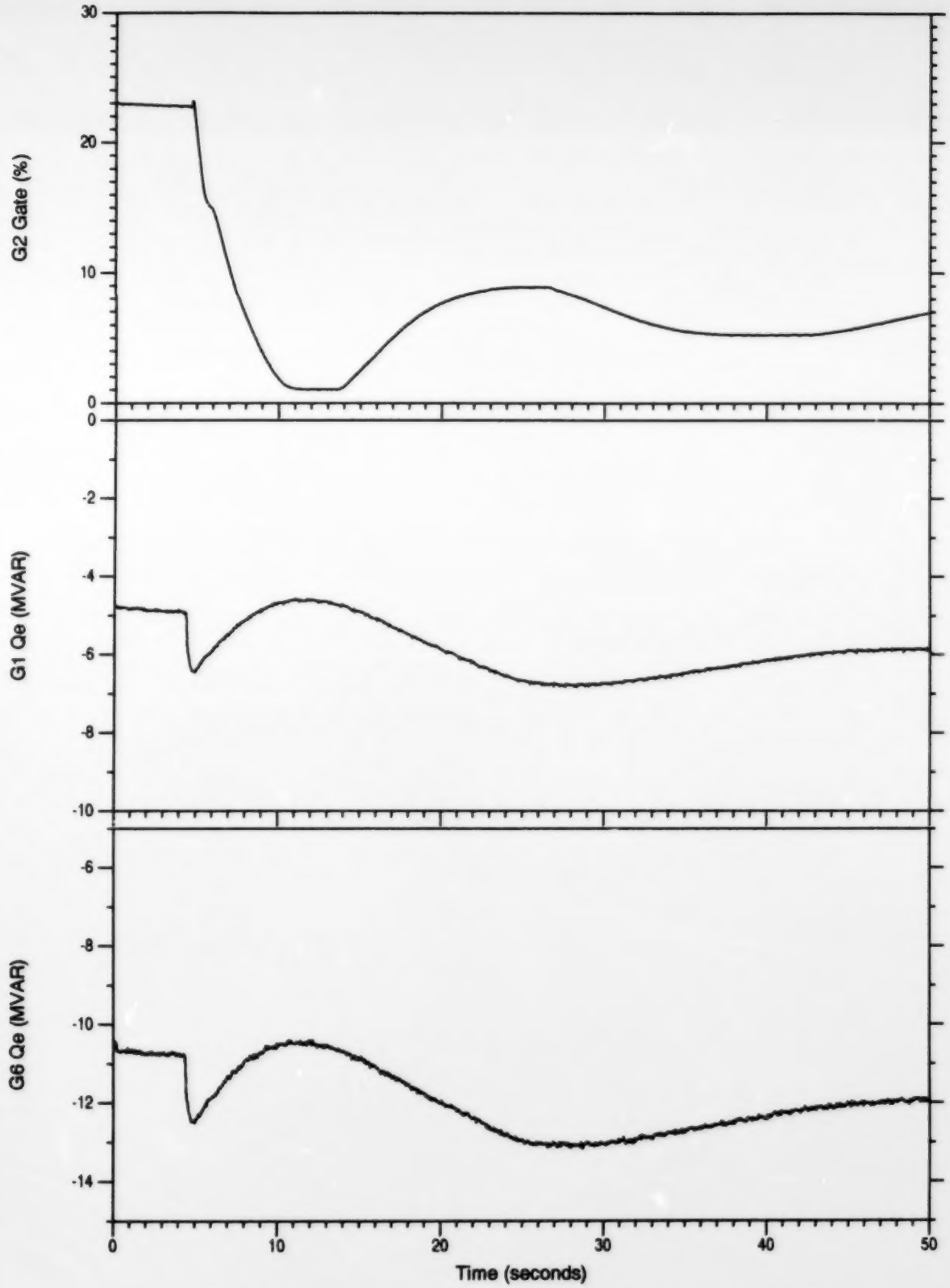

Figure 3d: NIAGARA 25 Hz ISLANDED TESTS, MARCH 4, 1991 REJECTION OF SAB I G2 FROM 5 MW, OP UNITS I/S

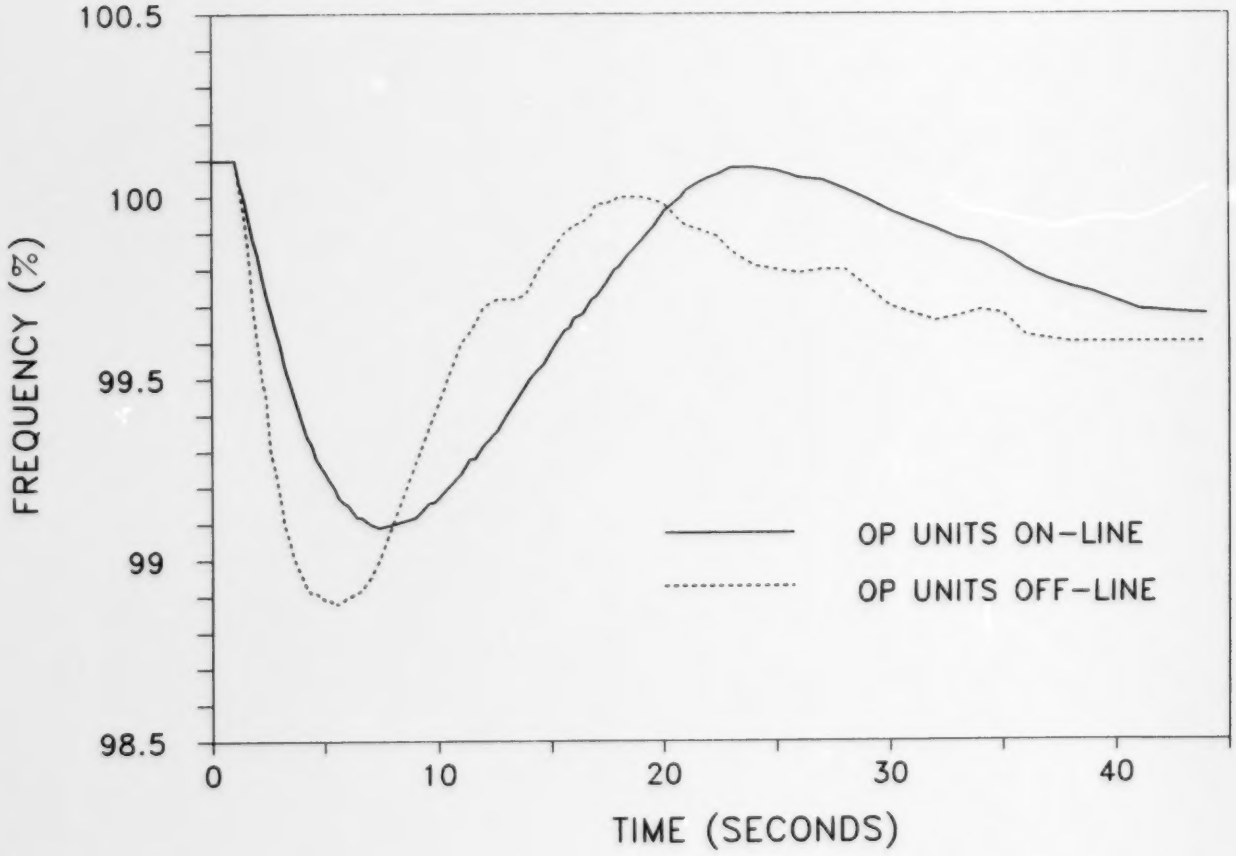

FIGURE 4 : NIAGARA 25 Hz ISLANDED TESTS, MARCH 4, 1991
SYSTEM FREQUENCY RESPONSES TO 5 MW GENERATION REJECTION

SYSFIG4.DRW

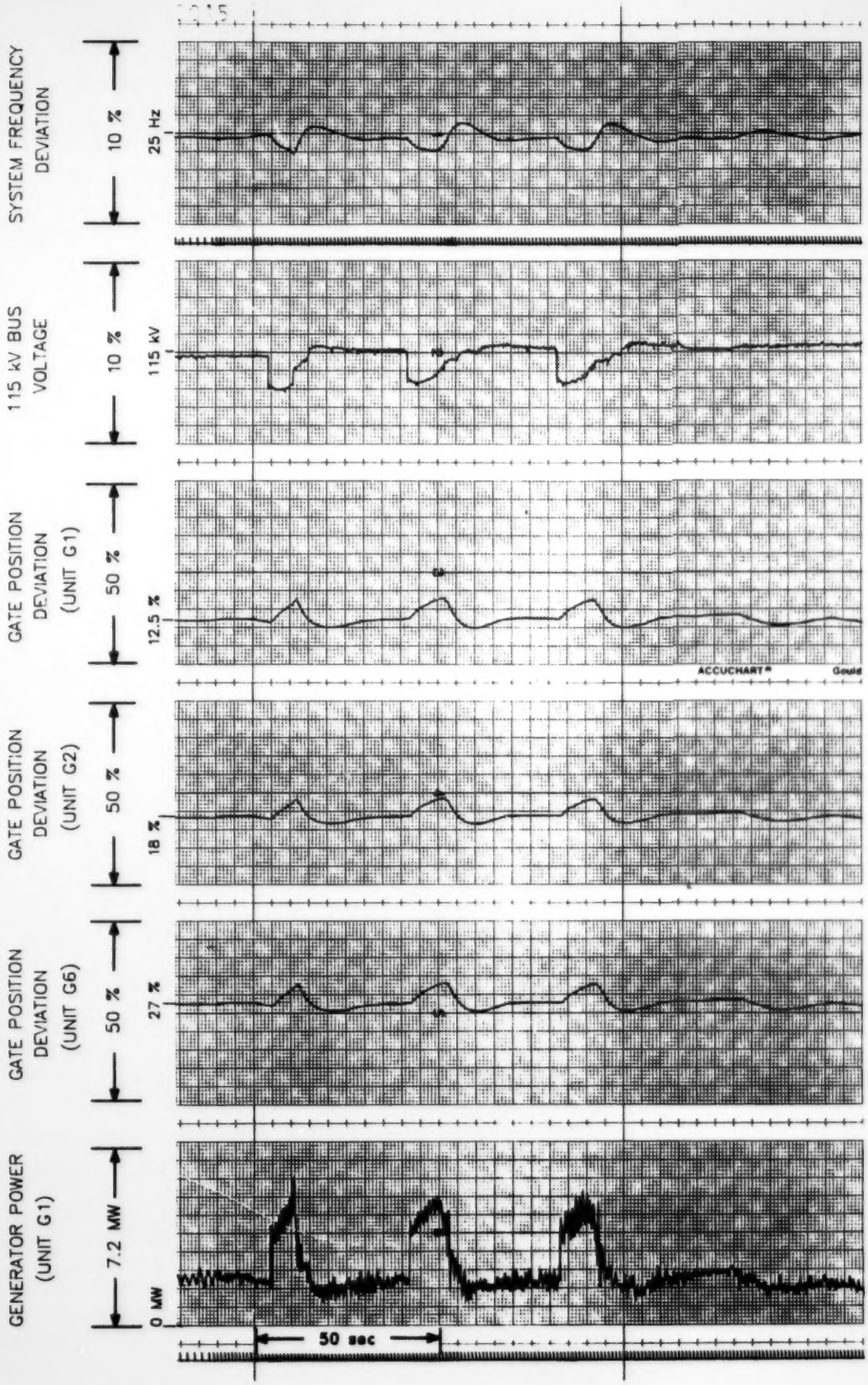

FIGURE 5a: S.A.BECK GS 1: ISLANDED OPERATION TESTS, MARCH 4, 1991
STELCO MOTOR START (9800 HP), STELCO COLD ROLL MILL off-line, OP & CNP off-line

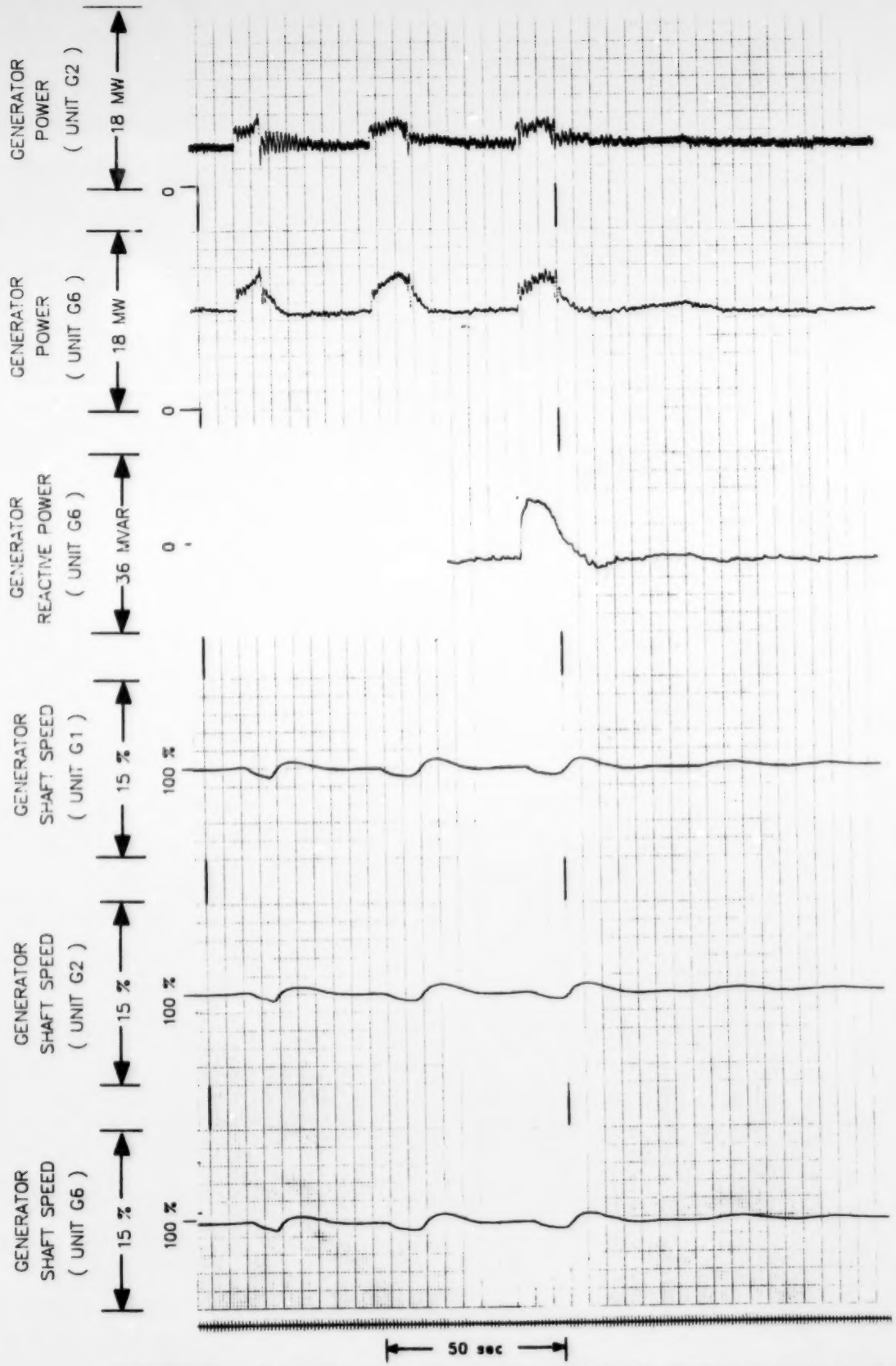

FIGURE 5b : S.A.BECK GS I ISLANDED OPERATION TESTS, MARCH 4, 1991
STELCO MOTOR START (9800 HP), STELCO COLD ROLL MILL off-line, OP & CNP off-line

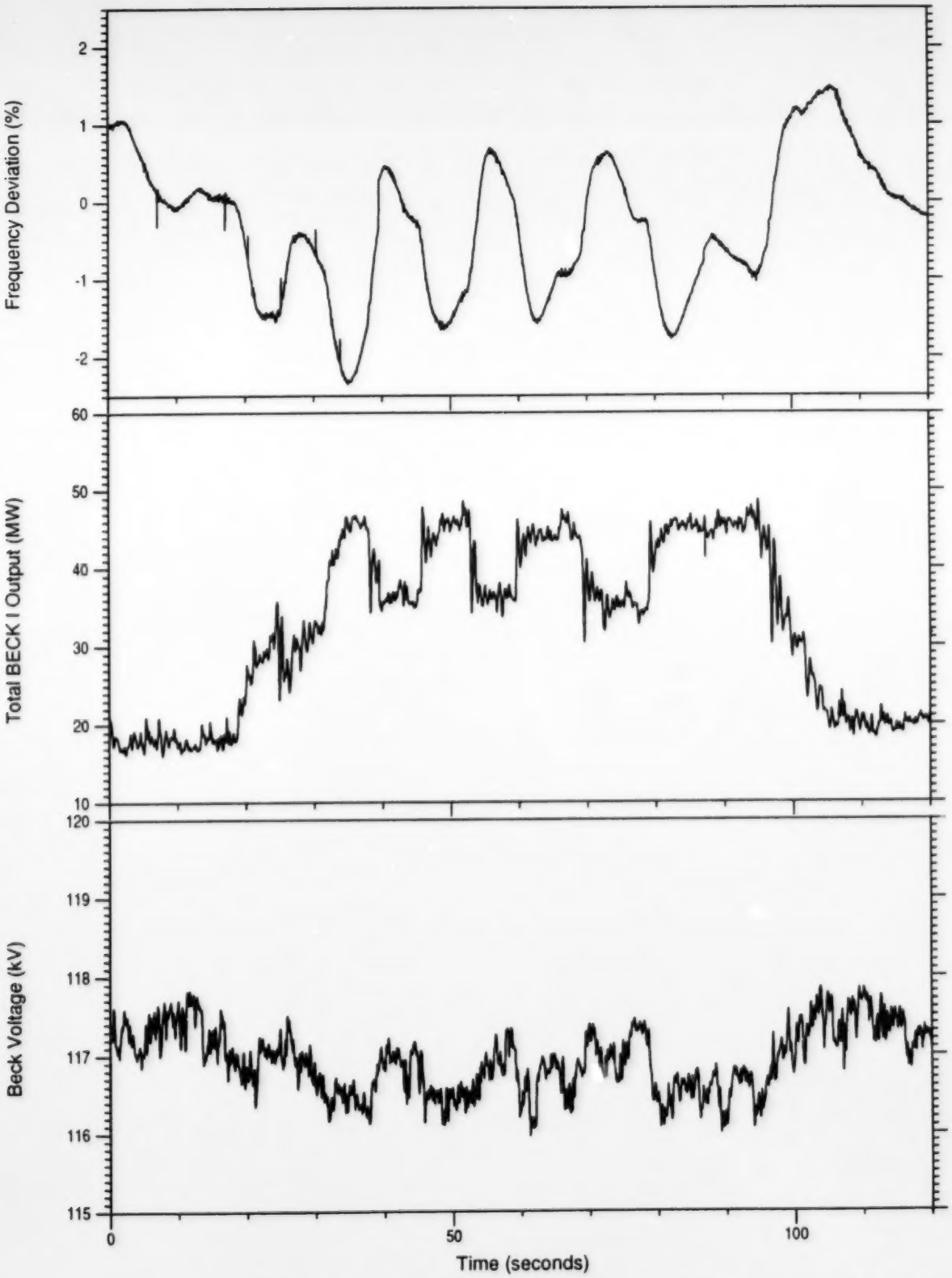

Figure 6a: NIAGARA 25 Hz ISLANDED TESTS, MARCH 5, 1991
STELCO LOAD VARIATIONS: G1, G2 and G6 on-line

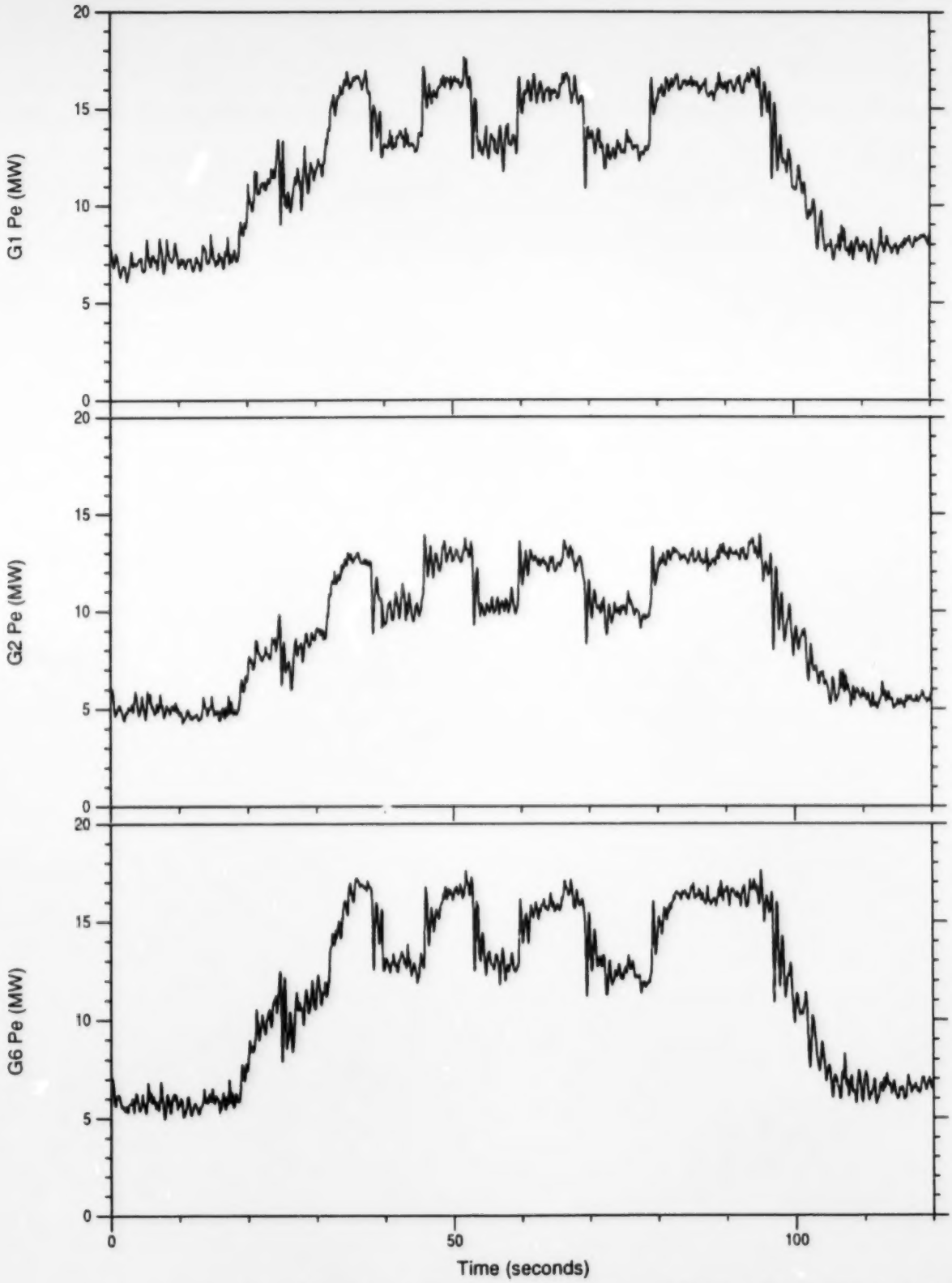

Figure 6b: NIAGARA 25 Hz ISLANDED TESTS, MARCH 5, 1991
STELCO LOAD VARIATIONS: G1, G2 and G6 on-line

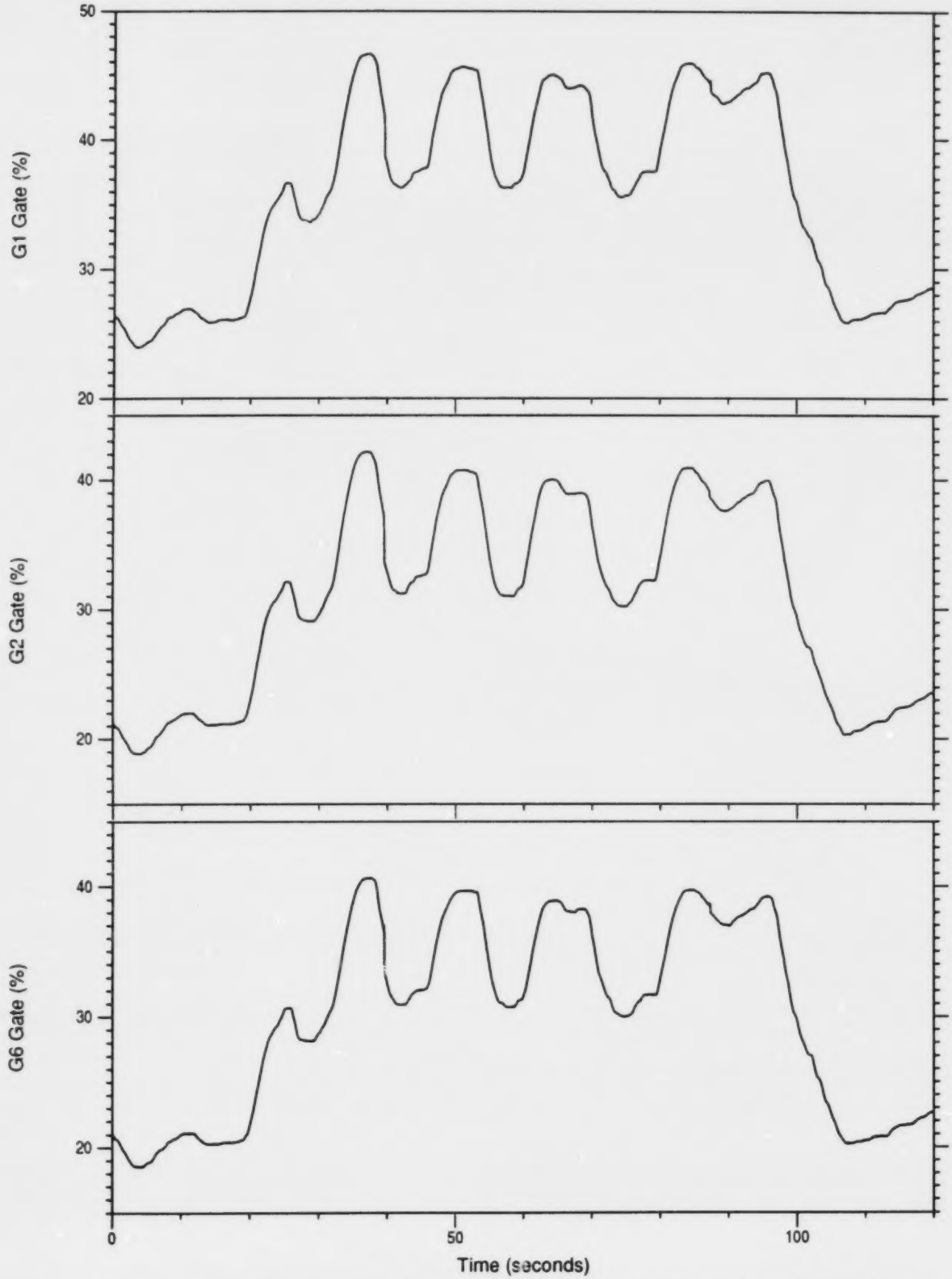

Figure 6c: NIAGARA 25 Hz ISLANDED TESTS, MARCH 5, 1991
STELCO LOAD VARIATIONS: G1, G2 and G6 on-line

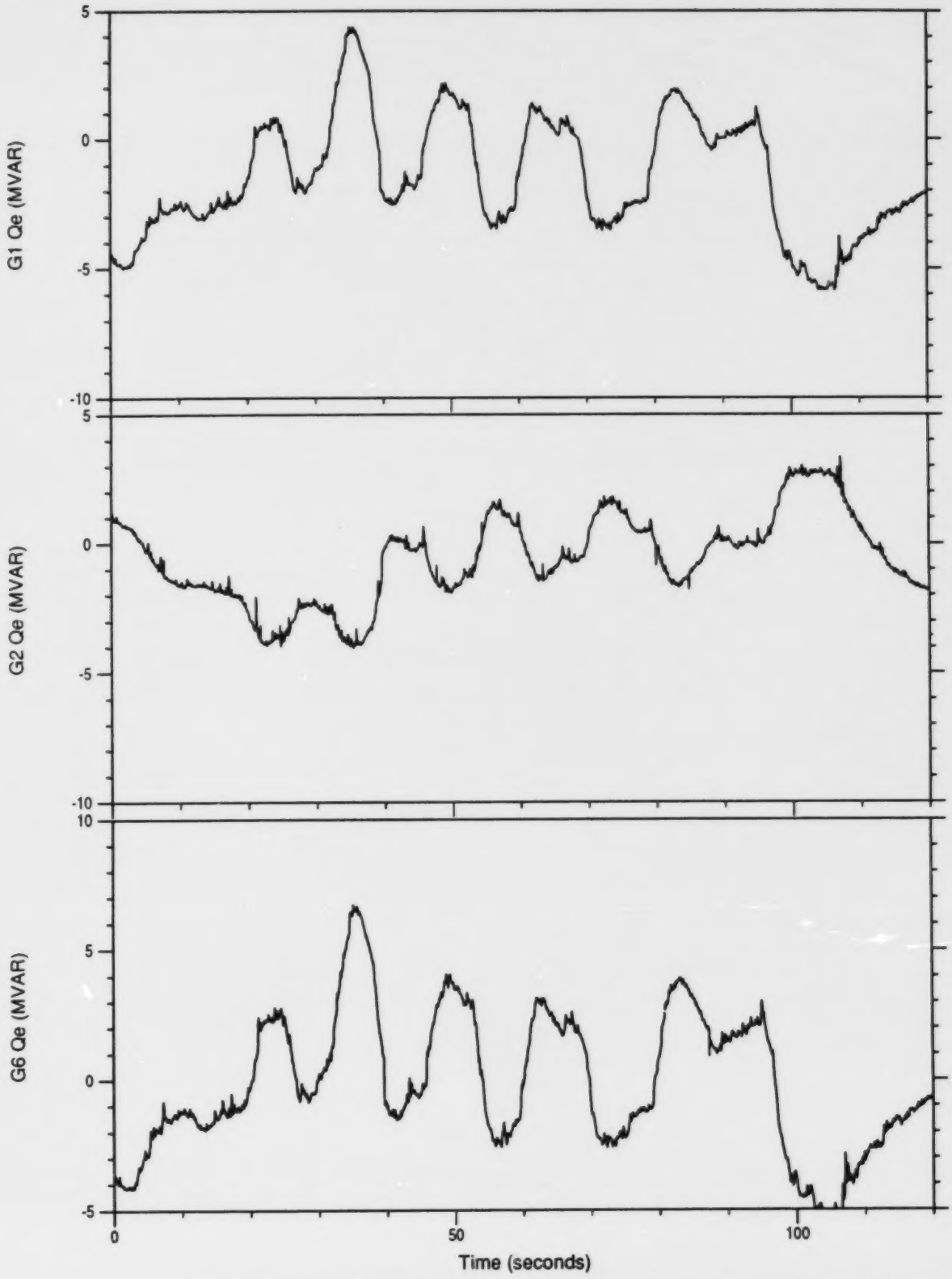

Figure 6d: NIAGARA 25 Hz ISLANDED TESTS, MARCH 5, 1991 STELCO LOAD VARIATIONS: G1, G2 and G6 on-line

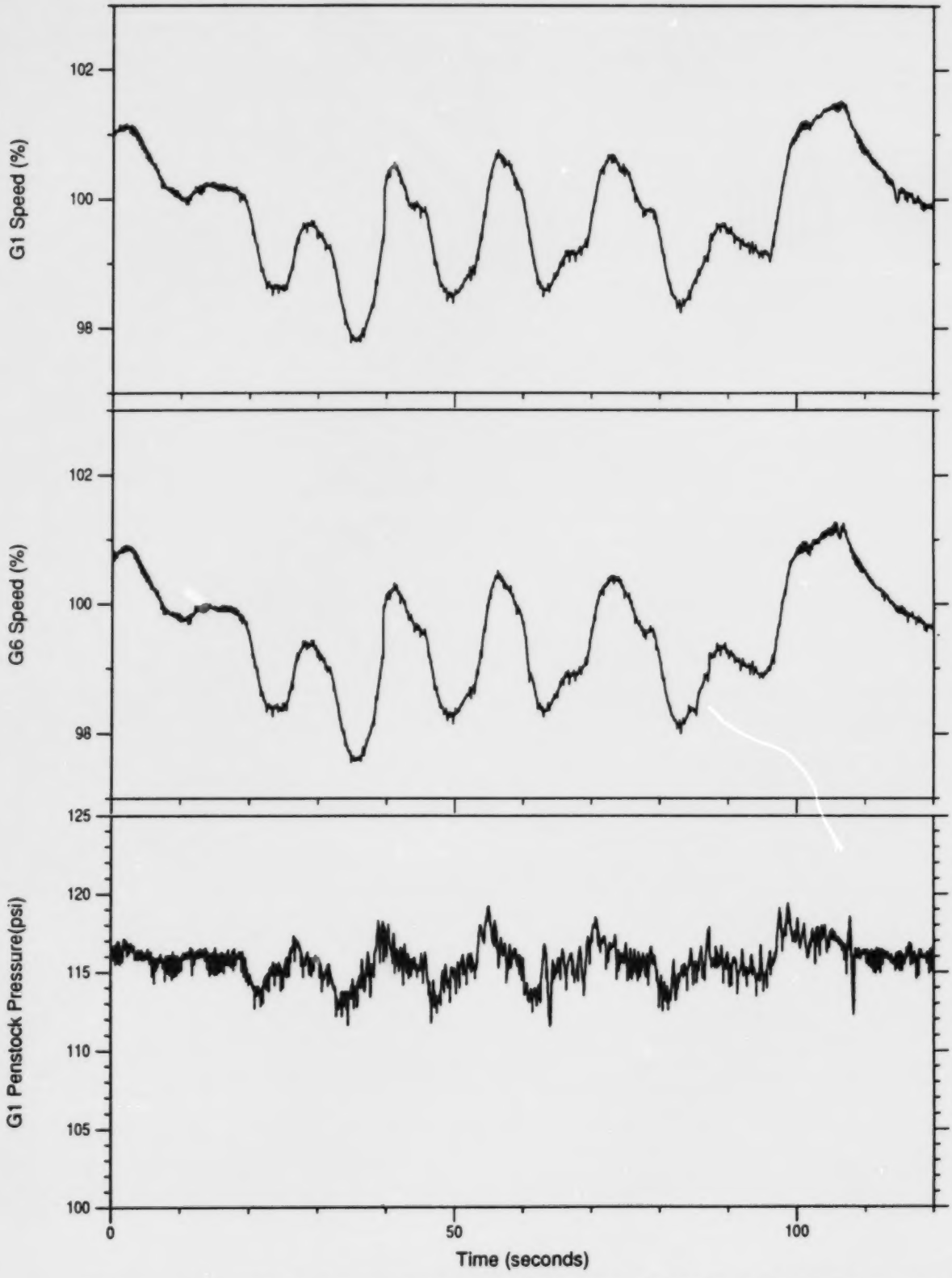

Figure 6e: NIAGARA 25 Hz ISLANDED TESTS, MARCH 5, 1991
STELCO LOAD VARIATIONS: G1, G2 and G6 on-line

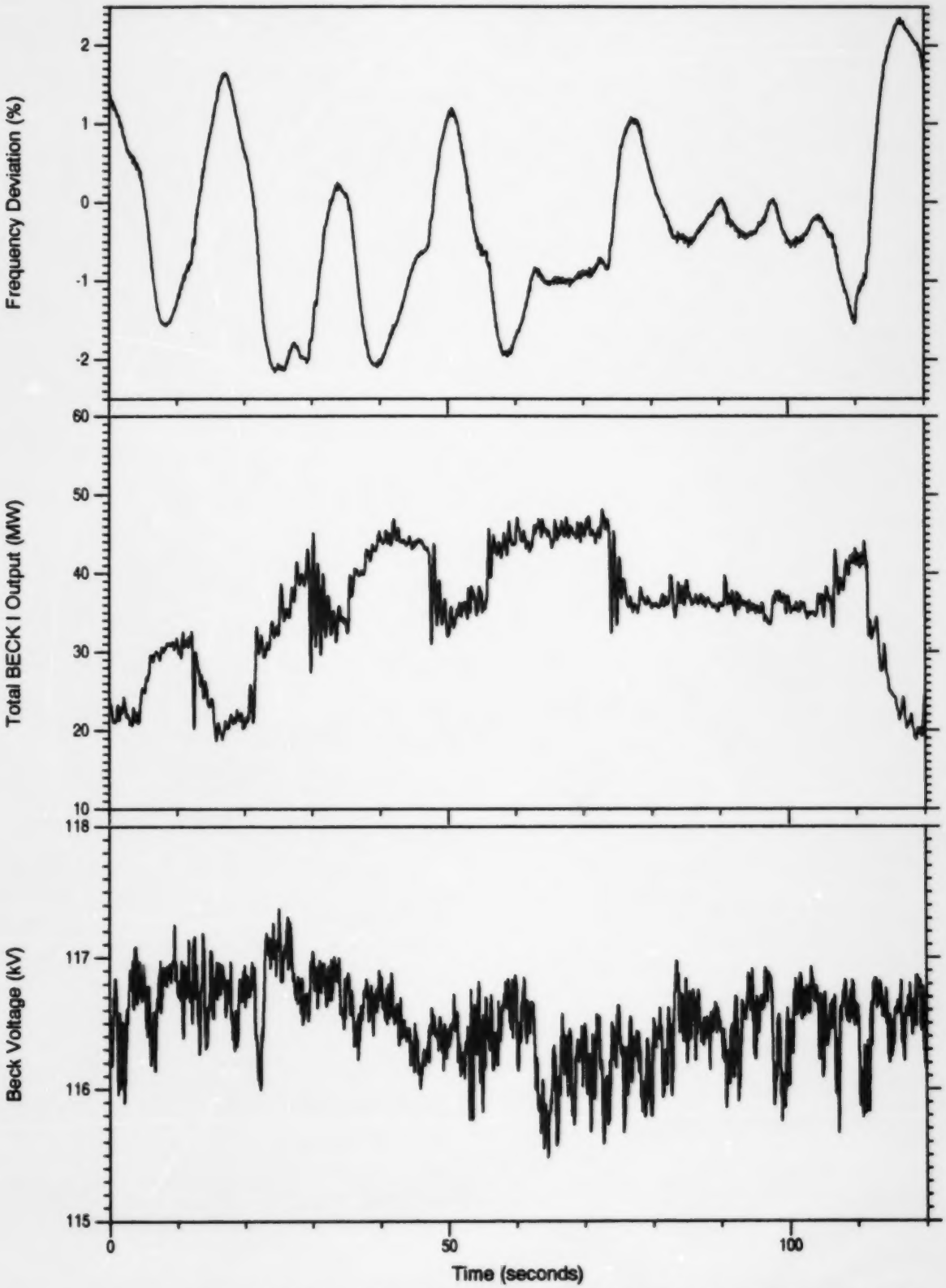

Figure 7a: NIAGARA 25 Hz ISLANDED TESTS, MARCH 5, 1991
STELCO LOAD VARIATIONS: G1, and G6 on-line

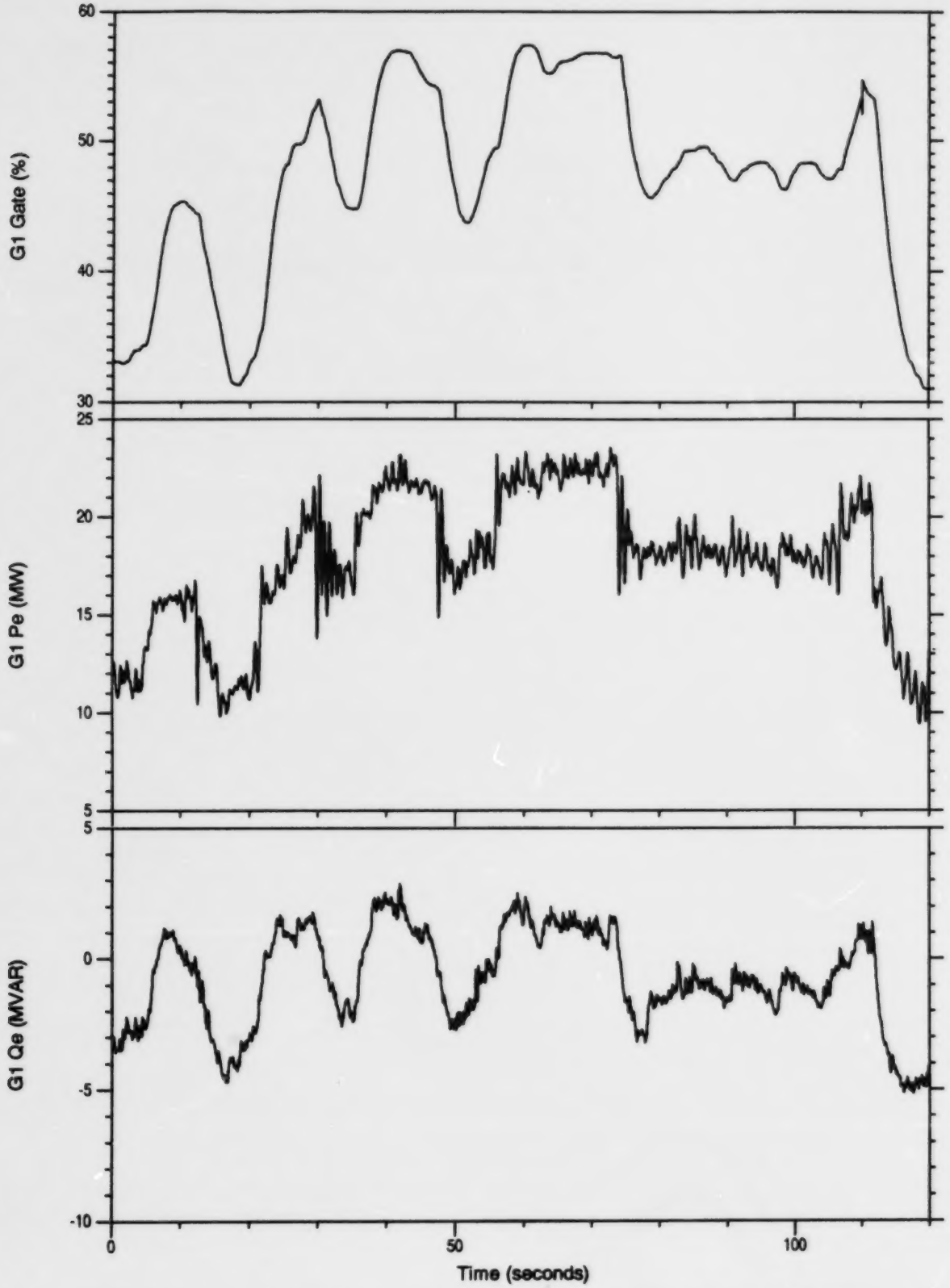

Figure 7b: NIAGARA 25 Hz ISLANDED TESTS, MARCH 5, 1991 STELCO LOAD VARIATIONS: G1, and G6 on-line

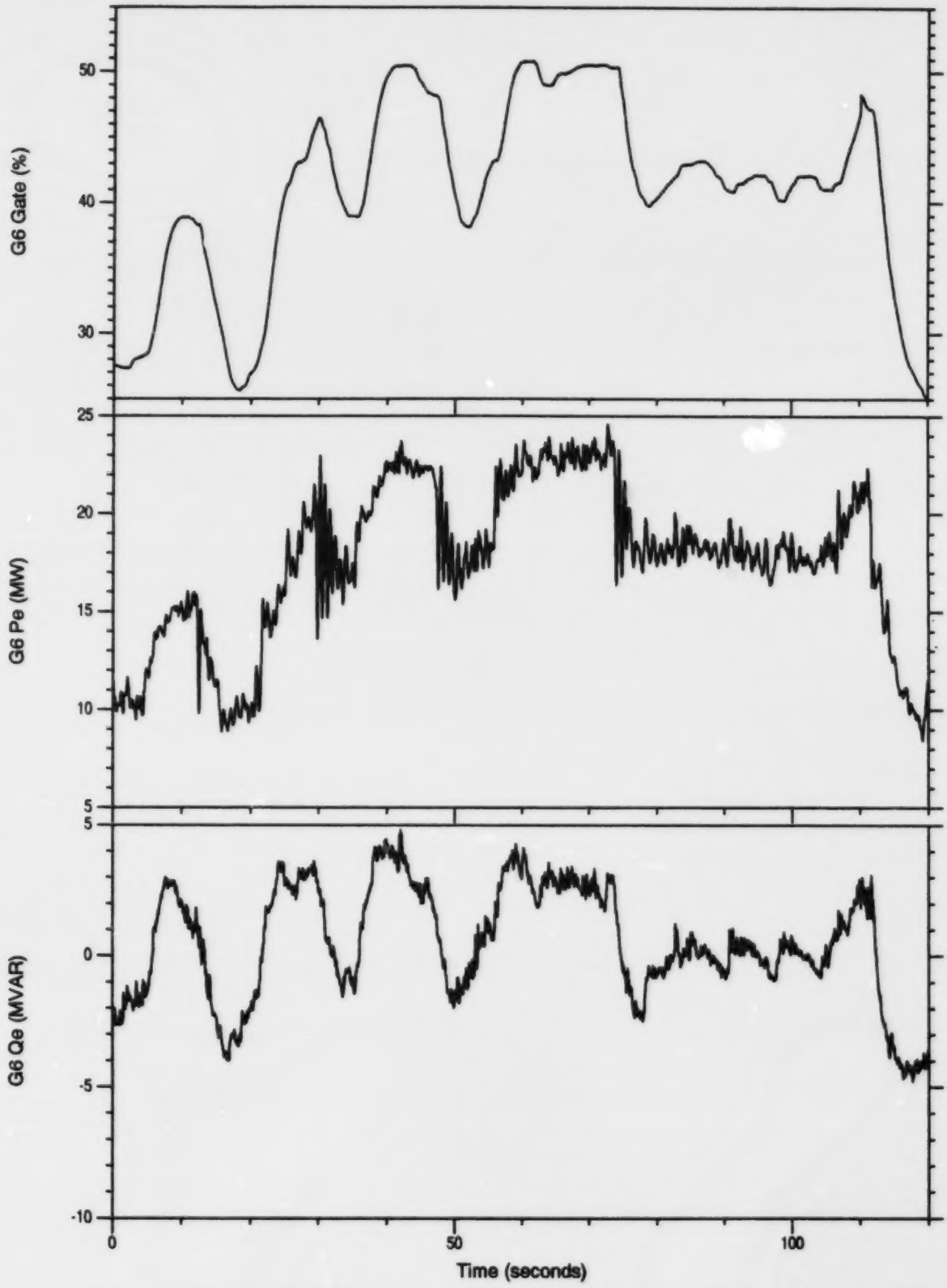

Figure 7c: NIAGARA 25 Hz ISLANDED TESTS, MARCH 5, 1991 STELCO LOAD VARIATIONS: G1, and G6 on-line

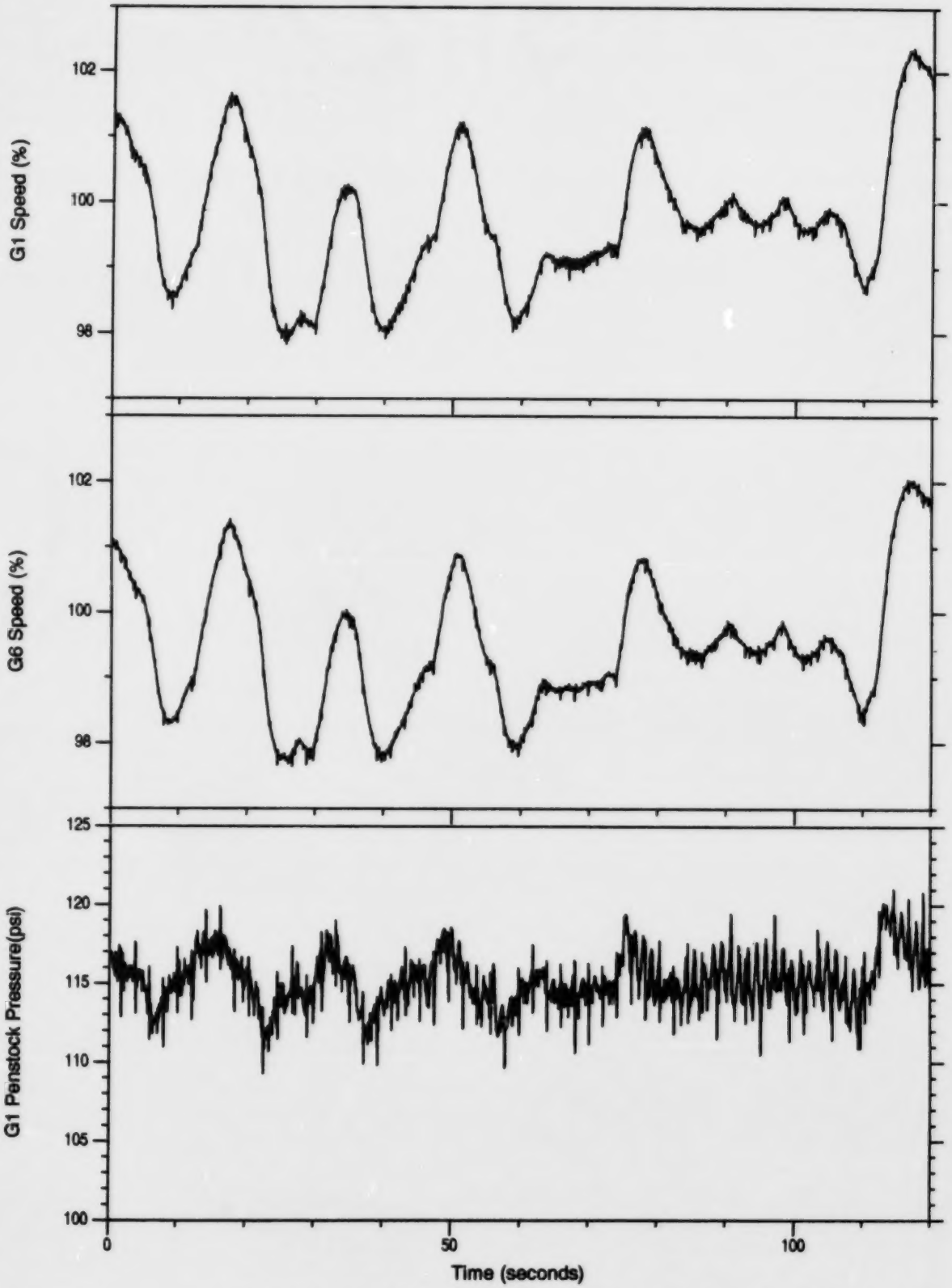

Figure 7d: NIAGARA 25 Hz ISLANDED TESTS, MARCH 5, 1991 STELCO LOAD VARIATIONS: G1, and G6 on-line